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BRL

COMBUSTIBLE CARTRIDGE CASE BALLISTIC CHARACTERIZATION

JOSEPH W. COLBURN
FREDERICK W. ROBBINS

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BALLISTIC RESEARCH LABORATORY
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The combustible cartridge case is widely used in modern ammunition systems. Its mechanical strength allows it to replace metallic packaging in the handling, storage, and loading phases, while its combustible nature eliminates the logistical burden of disposing of unconsumed packaging after firing.

Despite its wide use, the effect of the combustible cartridge case on final performance is not understood well enough to be modeled in a phenomenologically reasonable manner in modern interior ballistic codes. Current codes use three methods to represent the function of the combustible case. One method uses a tabular input; the others model the case as a propellant or as a surface function using case thermochemistry and burning rates as inputs. These procedures may induce errors because of uncertainties in the burning characteristics of the case material.

This paper briefly describes the closed bomb and blow-out bomb experiments performed on the case materials. Post impregnated combustible cartridge case and beater additive combustible cartridge case burning rate data are presented and compared. Combustion characteristics are highlighted, and a path for the development of a combustible case model for use with modern interior ballistic codes is suggested.

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I. INTRODUCTION

The combustible cartridge case has become an integral part of many modern weapons systems. Its volume and burning characteristics can have significant effects on the interior ballistic cycle.[1] Modeling a system which contains a combustible case element is complicated by a lack of understanding of the burning mechanism of the combustible case in a gun environment. Modeling efforts are further complicated by the existence of many types of combustible case material which are manufactured by different processes with different concentrations of nitrocellulose. A complete description of the combustion mechanism of each type of combustible cartridge case, including any effects produced by gun system geometry, is necessary for the further development of interior ballistic computer models, and the use of those models as development tools.

Of recent interest at the Ballistic Research Laboratory (BRL) is the application of the combustible case to the 155-mm howitzer system and the 120-mm tank gun system. In the 155-mm system, the combustible case has replaced the awkward bag charge and simplified auto-loader design. In the 120-mm system the combustible cartridge case has replaced a sturdier steel case. The structural benefits of steel have been outweighed by the logistic and performance benefits of combustible materials.

The results of this study will apply primarily to further development of the 120-mm tank gun system. The findings may also be applicable to other gun systems which take advantage of combustible cartridge case technology.

II. COMBUSTIBLE CASE TYPES

The combustible cartridge cases currently used by the U.S.Army in fielded systems are manufactured by two distinct processes. The 120-mm tank gun system is presently equipped with a case that is manufactured by the post impregnation process. The 155-mm, M203A1 howitzer charge utilizes a case made by the beater additive process. Because of manufacturing safety and efficiency considerations the beater additive process is considered as a candidate for use in the 120-mm system.

Both manufacturing processes utilize nitrocellulose fiber, kraft wood fiber, and a resin binder, although the percentage of each ingredient varies according to the specific application. The primary difference between the processes is that the resin is mixed in with the other ingredients before molding in the beater additive process, while in the post impregnation process, the case is dipped in resin after molding.[2] Post impregnated cases have shell-like, high resin density regions near their outer surfaces and a very low resin density in the interior, while a beater additive case has a much more uniform resin density, and is much more flexible. Figure 1 shows how resin density varies with distance from the outer case wall in cases formed using the two processes. Reference 2 contains a complete description of both processes, along with the history of the combustible case, and ideas for future development.

For the purpose of our study we also included an inert case. This case was composed entirely of kraft wood fiber and resin binder, with no nitrocellulose at all. The inert case was useful in gun firings where it was desirable to occupy the volume of a combustible cartridge case and simulate its compressibility, without adding to the combustion process. After inert case gun firings most of the inert material was recovered from the gun chamber intact.

Several of the experimental gun firings were conducted without a cartridge case. In this situation the propellant was held in place with two cloth bags to simplify the loading process. The no case scenario allowed the establishment of a base line, propellant only data set, which simplified comparisons with computer models by removing the complexities of modeling a combustible case. Care was taken during the bag loading process to insure a constant propellant density throughout the chamber. An uncontrolled distribution of ullage through the charge would have added an additional unknown to the modeling process, and reduced confidence in the results.

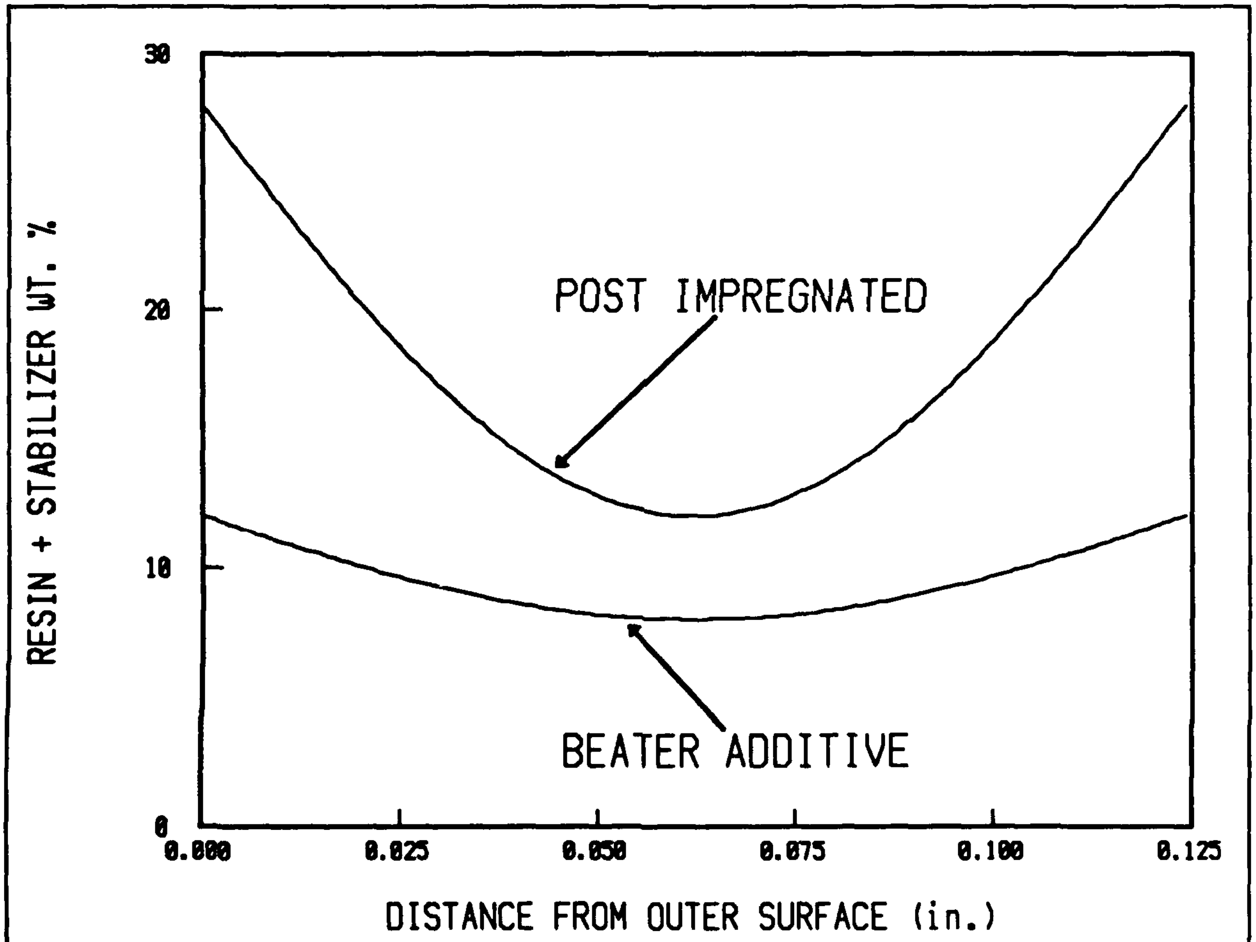

Figure 1. Resin & Stabilizer Concentration Profiles [2]

III. EXPERIMENTAL

This study involved several different interior ballistic diagnostic techniques. Closed bomb tests were conducted to determine the apparent burning rates of combustible case samples and propellant samples. Interrupted burner tests were conducted to get a qualitative idea of how the case material breaks-up while burning. Gun firings were conducted to determine what effects the different case types had on macroscopic ballistic parameters, and to act as references for the computer models.

A. CLOSED BOMB / CCC BURNING RATE

A series of closed bomb tests were performed in an effort to obtain apparent burning rate and sample size dependence data for the beater additive (BA) and post impregnated (PI) case materials. A total of eighteen closed bomb tests were made on the beater additive and post impregnated case types. The loading density of each charge was maintained at 0.25 g/cc, while the combustible case samples were varied between three different sized discs. The loading density was kept constant so that relationships could be seen between sample size (disc diameter) and apparent burning rate. A representative plot of apparent burning rate versus pressure for each sample size and case type is presented in Figure 2. Appendix B contains data listings for each combustible cartridge case closed bomb firing.

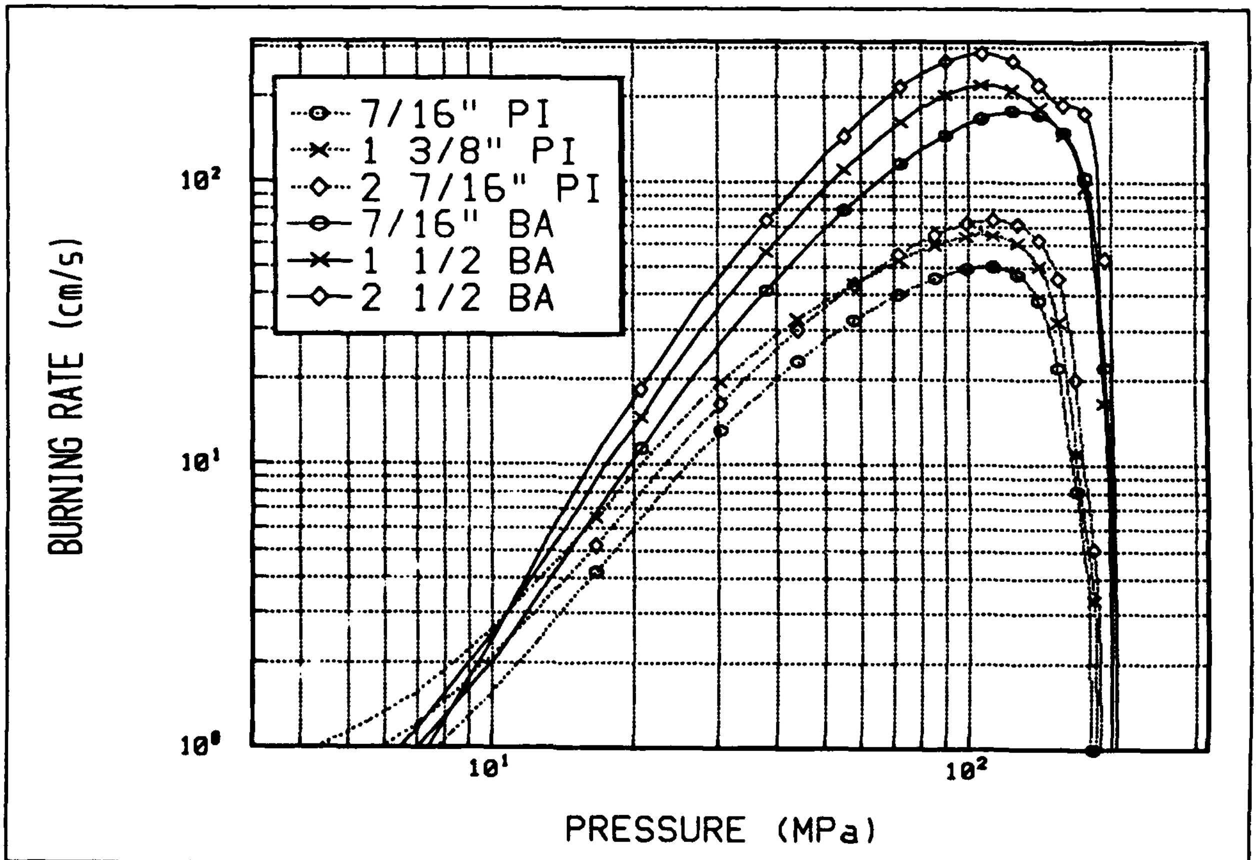

Figure 2. Apparent Burning Rates For Case Material

The beater additive material showed significantly higher apparent burning rates than similarly sized post impregnated case material. Since the energy content of the two case types is nearly identical it was presumed that the difference in resin distribution affected the apparent burning rate of the combustible case material. The magnitudes of the apparent burning rates and the differences in burning rate associated with sample size lead us to believe that the burning mechanism for combustible case materials is something other than would be expected for a nitrocellulose based propellant of similar shape and size.

Analysis and form function techniques more complex than the initial assumption of simple, uniform density, discs are necessary to model the burning mechanism of combustible case discs in the closed bomb environment.

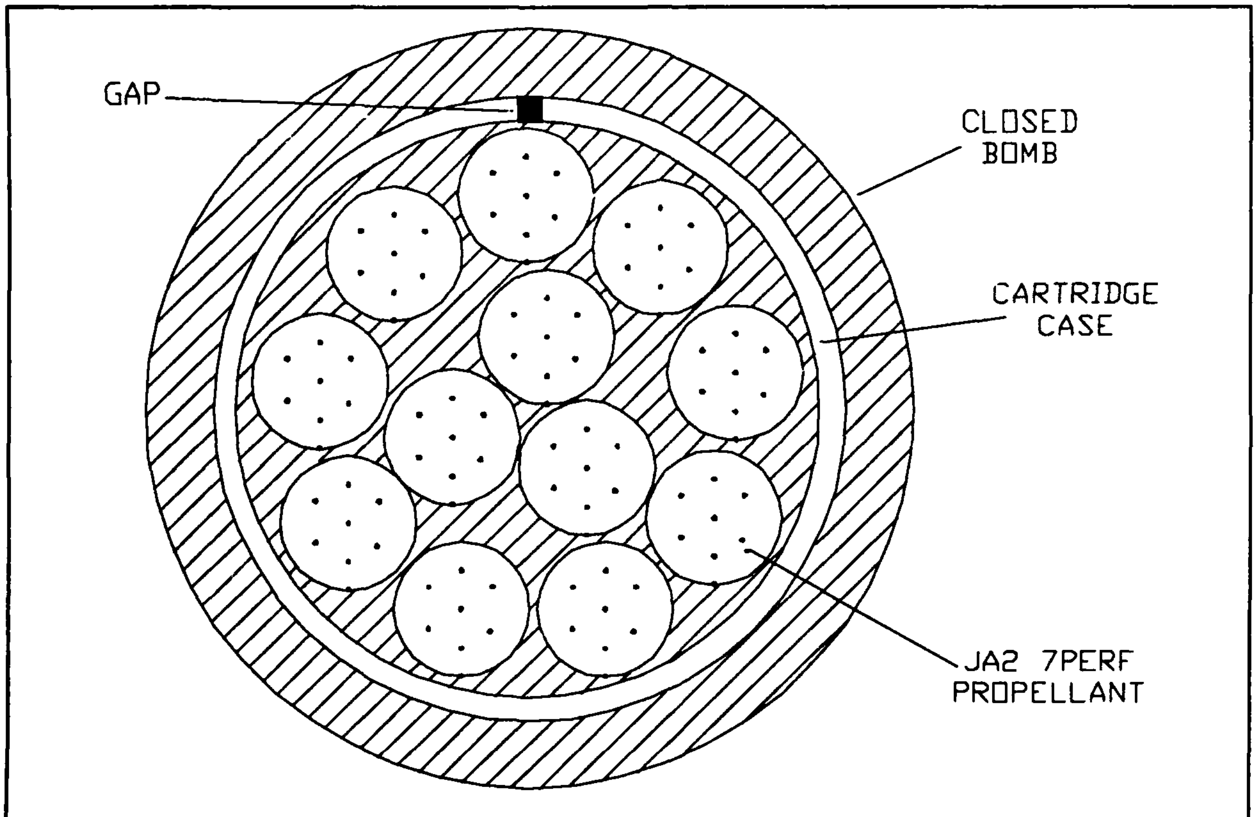

Figure 3. Interrupted Burner Configuration

B. INTERRUPTED BURNER

A series of interrupted burner tests were conducted on the beater additive and post impregnated case materials to gain a qualitative understanding of how the two case materials burn in a gun environment. A total of eleven tests were conducted with the two types of case material. For each round the chamber was lined with a cylinder of case material, then filled with approximately 72 grams of JA2, 7 perforation, granular propellant as shown in Figure 3. The JA2 was stacked in the chamber in an axi-symmetric manner. The charge was then initiated with a black powder ignition charge. Charge masses, burst pressures, and comments are shown in Table 1.

Table 1. Interrupted Burner Data					
CASE TYPE	CASE MASS (g)	JA2 MASS (g)	DESIGNED BURST PRESURE (MPa)	MAXIMUM PRESSURE (MPa)	COMMENTS ON RECOVERED CCC RESIDUE
post impreg.	26.0940	71.3820	34.5	>44.8	many CCC slivers
beater add.	24.7624	71.8184	34.5	>68.9	CCC "fuzz"
post impreg.	29.0720	71.9142	6.9	17.2	no residue
beater add.	26.3393	72.1131	6.9	17.2	large CCC chunks
post impreg.	27.1764	72.1866	34.5	55.2	many CCC slivers
beater add.	25.7230	71.8104	34.5	>68.9	large CCC chunks
post impreg.	27.4016	71.9783	68.9	68.9	many CCC slivers
beater add.	25.8464	71.4461	68.9	89.6	large CCC chunk
post impreg.	28.3219	71.9595	34.5	58.6	some CCC slivers
beater add.	25.9096	71.5074	34.5	62.1	lg. & sm. CCC chunks
post impreg.	29.1016	72.1278	34.5	56.5	many CCC slivers
none	0.0	77.6745	34.5	48.3	N/A
none	0.0	77.3005	34.5	48.3	N/A

In general the interrupted burner technique was not very effective with combustible cartridge case material because the case material that had not been consumed before the burst disc ruptured continued to burn or smolder after disc rupture. This limited sample recovery to only the larger case pieces which were manually extinguished before they were completely consumed.

The recovered case pieces were quite interesting. The post impregnated case pieces consisted exclusively of material from the high resin density layer which was adjacent to the chamber wall. The high resin density layer adjacent to the propellant and the inner low resin density region had burned away completely.

The recovered beater additive case pieces showed mechanical damage, and in some cases charring from post-burst burning, but all pieces appeared to be nearly the full thickness of the pre-test samples. This indicated that the beater additive case sections which were ignited, burned away completely, while the unignited portions, which were probably farther from the ignition charge and closer to the burst disc, were not involved in combustion before the disc ruptured.

The results indicated that the beater additive case burned more uniformly than the post impregnated case, presumably because of the more uniform resin density in the beater additive case samples.

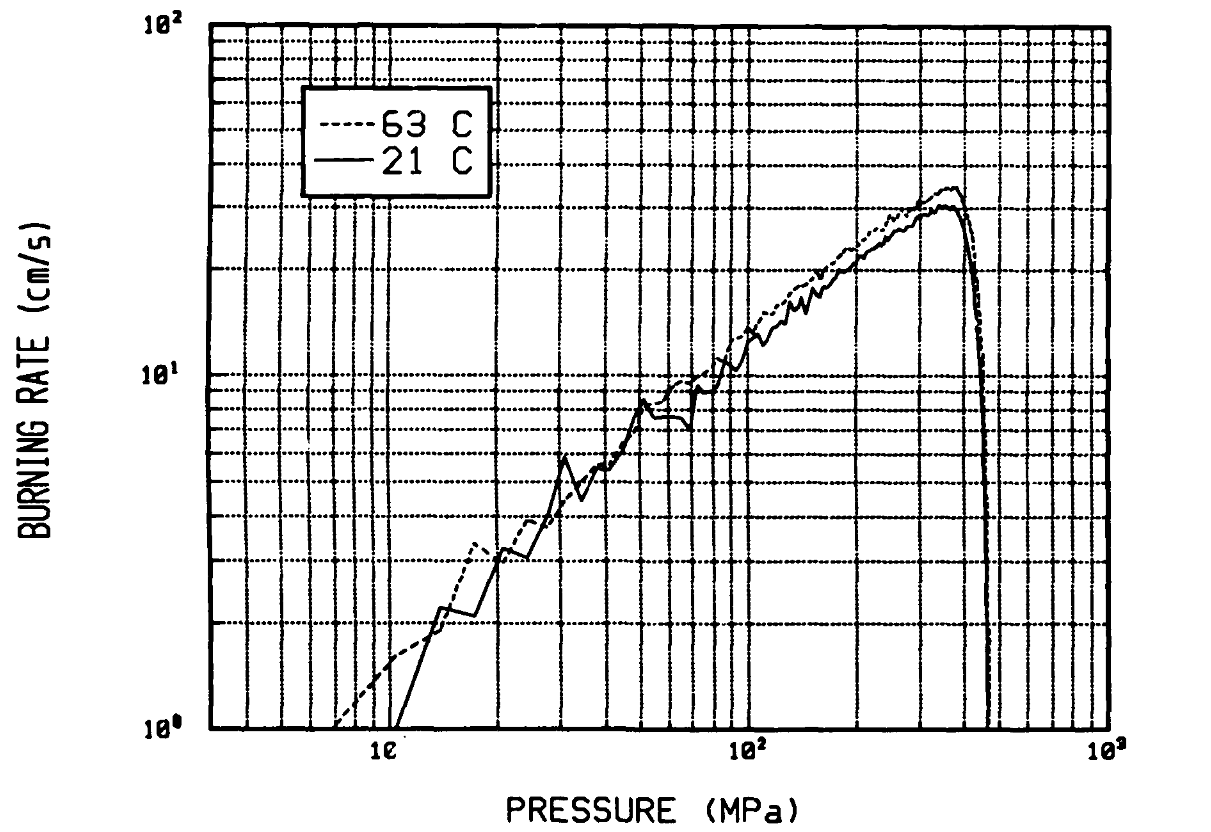

Figure 4. JA2 Burning Rates at 21C and 63C

C. CLOSED BOMB / JA2 BURNING RATE

A series of closed bomb firings were performed to determine the burning rates of the JA2 propellant used in the test rounds. Closed bomb firings were conducted at both 21 C and 63 C so that accurate burning rate data could be included in the data bases for computer modeling. Representative burning rate data are presented in Figure 5. Appendix A contains data listings for the JA2 closed bomb firings.

D. GUN FIRINGS

Gun firings were conducted at the Ballistic Research Laboratory's Sandy Point Test Facility. The gun was instrumented with thirteen Kistler model 6211 pressure gages. Velocities were measured with a 10.5 GHz WEIBEL down-range doppler radar system, and with a pair of WEIBEL Sky Screens centered 36 meters from the muzzle. Data were taken on the PDP11-45 based BALDAS system, and on the HP9020/Multitrap based TARPS (Telemetry Acquisition Reduction and Plotting System) data acquisition system. The firing matrix for the test rounds is shown in Table 2, along with the round identifier codes. Peak pressure data are shown in Table 3, and velocity data are shown in Table 4.

Table 2. DM13 Firing Matrix			
ROUND IDENTIFIERS	CASE TYPE	No. of ROUNDS	CONDITIONING TEMPERATURE
PI 1 & PI 2	post impregnated	2	21 C
PI 3 & PI 4	post impregnated	2	63 C
BA 1 & BA 2	beater additive	2	21 C
I 1 & I 2	inert	2	21 C
NC 1 & NC 2	no case	2	21 C
NC 3 & NC 4	no case	2	63 C

The gun firings were designed to quantify the effects of different cartridge cases on measurable ballistic parameters. A series of nineteen test rounds were fired to compare the characteristics of the different cartridge case types, and to establish a data base for comparison with computer models. The test rounds were based on the German 120-mm DM13, APFSDS round, shown in line diagram form as Figure 6. This round was chosen because of its relatively high availability, and because it had well documented performance characteristics. A nominal DM13 consisted of a post impregnated combustible cartridge case, a bayonet primer, a projectile/sabot assembly, and a nominal 7.32 kg of seven perforated JA2 granular propellant. Seven of the rounds were left unaltered and used as check out rounds for the data acquisition systems. These rounds were expected to give performance similar to that of the rounds equipped with a post impregnated case. The other twelve rounds were broken down then reassembled as per the matrix shown in Table 2.

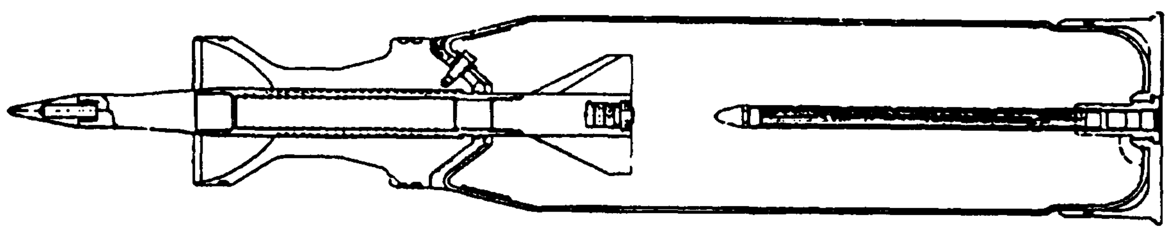

Figure 5. DM13 Line Drawing

The no case rounds formed a base line database for computer code analysis of the test rounds. By removing the complex combustible case component from the input database an approximation of the resistive pressure profile of the DM13 round could be formulated, and used as a known variable for analysis of subsequent rounds with more complex input databases. These firings were done at both 21 C and 63 C.

The inert case rounds were fired to define the effects of the case's volume and compressibility on the ballistic cycle. The inert case occupies the same volume as a combustible case but it burns very little during the ballistic event. After firing each of the inert case rounds a significant

portion of each inert case was recovered intact. The portions of the case which were missing appeared to have been removed by mechanical means , not consumed by combustion.

The post impregnated case rounds were fired at both 21 C and 63 C. These rounds provided experimental comparison data for use with the model of the post impregnated case.

The beater additive case rounds provided data for use with the case modeling effort, and made an interesting comparison between identical rounds equipped with post impregnated and beater additive cases. Additional gun firing data are shown in Appendix D.

Table 3. DM13 Firing Data, Peak Pressures											
	DISPLACEMENTS FROM BREECH IN cm										
ID	9.5	28.6	48.9	76.8	104.8	153.0	229.2	305.4	381.6	457.8	534.0
I1	366	370	346	303	289	249	206	173	129	97	75
I2	362	367	342	302	287	252	193	170	125	92	71
NC1	340	347	328	283	272	240	201	161	131	95	66
NC2	341	348	330	278	281	241	187	172	125	96	74
NC3	432	430	419	348	348	287	232	155	103	79	59
NC4	428	428	416	346	348	---	224	160	108	79	59
PI1	478	479	462	373	342	296	217	166	124	85	62
PI2	471	463	445	373	350	311	219	162	---	83	61
PI3	569	557	536	539	433	379	232	155	104	79	50
PI4	583	570	550	454	432	335	233	158	106	82	47
BA1	486	488	456	382	345	290	228	173	117	82	56
BA2	494	482	464	380	349	286	215	166	116	84	61
(All Pressures In MPa)											

Table 4. DM13 Firing Data, Velocities			
ROUND ID	DOPPLER MUZZLE VELOCITY (m/s)	DOPPLER VELOCITY @ 36 meters (m/s)	SKYSCREEN VELOCITY @ 36 meters (m/s)
I1	1523	---	1521
I2	1524	1523	1522
NC1	1495	---	1493
NC2	1495	1493	1494
NC3	1582	1580	---
NC4	1583	1581	1587
PI1	1624	1623	1625
PI2	1628	1624	1623
PI3	1688	1686	1692
PI4	1699	1697	1705
BA1	1639	1636	---
BA2	1639	1636	1636

E. RESULTS

The significant difference between the apparent burning rates for the post impregnated and beater additive case materials in the closed bomb tests indicate that the two case types have different burning characteristics. This may necessitate the use of different form functions, models, or techniques when modeling the cases with interior ballistic codes.

The collected gun firing data provide no new charge performance information, just performance levels to be emulated by interior ballistic computer modeling programs. The specific pressure levels recorded are not of general interest to the ballistic community, but the comparison of those levels can be quite interesting.

As detailed in Table 3 the difference between the average chamber pressures of the inert case and no case rounds fired at 21 C is 24 MPa. This is the difference expected because of the volume occupied by the inert case. The pressure difference also indicates that the portion of the propellant placed in each bag in the no case charges more closely approximated the configuration of an unaltered round. This is different from previous work[1] where the expected pressure difference was not seen due to excessive ullage in the forward propellant bag.

The other breech pressure difference of interest is that between the beater additive case rounds and the post impregnated case rounds fired at 21 C. The difference suggests that the significant differences in the apparent burning rates seen in the closed bomb tests are also seen in the gun firings.

IV. COMPUTER MODELING

At this point in time the computer modeling portion of this study has not commenced. The primary phase of the modeling effort will use the lumped parameter code known as IBHVG2[3] to emulate the data obtained from our closed bomb experiments with both types of combustible case material. This iterative process consists of specifying a model for the cartridge case material, running IBHVG2 using that model, processing the pressure versus time data output from IBHVG2 with the closed bomb reduction program SIMPCB[4], and then comparing the SIMPCB output with the output from our experiments. When the model burning rates match those of the experiment, a possible model for both types of case material will have been specified. Then, the second phase of the case modeling study begins with adapting the IBHVG2 case model for use with the NOVA code.[5] A NOVA database will be specified for each set of experimental gun firings. A resistive pressure profile for the DM13 projectile will be determined by varying the profile in the NOVA input database for the no case rounds until the experimental pressures and velocity are matched. This resistive pressure profile, along with the combustible cartridge case model will be added to the NOVA databases for the other rounds. The combustible cartridge case model will then be adjusted to yield a satisfactory match with the experimental data.

V. CONCLUSIONS

An experimental database has been established for use in modeling the combustible cartridge case. A time consuming modeling effort has been suggested which would yield models for both the post impregnated and the beater additive combustible cartridge cases. These case models will be useful in modeling any 120-mm system with either the IBHVG2 or the NOVA interior ballistic codes. They can also be adapted for use with other gun systems which use a combustible cartridge case.

It has been shown that a 120-mm round equipped with a beater additive combustible cartridge case will produce measurably higher pressures and velocities than an identical round equipped with a post impregnated combustible cartridge case. The performance differences between the two case materials appear to be significant enough to warrant the attention of charge designers, should a transition to the beater additive case material ever be affected in the 120-mm system.

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APPENDIX A

JA2 CLOSED BOMB BURNING RATE DATA LISTING

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BURNING RATE DATA FOR JA2 PROPELLANT AT 21C

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
6.894757	0	162.0267	18.13629	317.1588	28.85152
10.34213	0	165.4741	17.88671	320.6062	29.04469
13.78951	2.213539	168.9215	18.26223	324.0535	29.62208
17.23689	2.083951	172.3689	18.88612	327.5009	29.26445
20.68427	3.268863	175.8163	19.08761	330.9483	29.40847
24.13164	3.074189	179.2636	20.21447	334.3957	30.30984
27.57902	3.988925	182.7110	19.91603	337.8430	30.74248
31.02640	5.867453	186.1584	19.75904	341.2904	30.53971
34.47378	4.402924	189.6058	20.15595	344.7378	30.15137
37.92116	5.449747	193.0531	20.34989	348.1852	30.24357
41.36854	5.422724	196.5005	20.99739	351.6326	30.48426
44.81592	6.096104	199.9479	21.20024	355.0799	30.53153
48.26329	7.578280	203.3953	22.03446	358.5273	30.27113
51.71067	8.543701	206.8427	22.07284	361.9747	29.93819
55.15805	7.639349	210.2900	21.53584	365.4221	30.05726
58.60543	7.698846	213.7374	22.49381	368.8694	30.41142
62.05281	7.658862	217.1848	22.75707	372.3168	30.48622
65.50019	7.623157	220.6322	23.14402	375.7642	30.30705
68.94757	7.005708	224.0796	23.04189	379.2116	29.97913
72.39494	9.457283	227.5269	23.48285	382.6590	29.37167
75.84232	8.936294	230.9743	24.01136	386.1063	28.87378
79.28970	9.080759	234.4217	23.39655	389.5537	28.13723
82.73708	9.385835	237.8691	23.91532	393.0011	27.39336
86.18446	10.98570	241.3164	24.93726	396.4485	26.87299
89.63184	10.72553	244.7638	24.44984	399.8959	25.79507
93.07921	10.37294	248.2112	24.82689	403.3432	24.55553
96.52659	11.09123	251.6586	25.51813	406.7906	23.48033
99.97397	12.52346	255.1060	25.92364	410.2380	22.39486
103.4213	12.86609	258.5533	25.89237	413.6854	21.43161
106.8687	13.29568	262.0007	26.27561	417.1327	20.05414
110.3161	12.23365	265.4481	26.21272	420.5801	18.65875
113.7634	12.82262	268.8955	26.06065	424.0275	17.32211
117.2108	13.75686	272.3429	26.12824	427.4749	16.31251
120.6582	13.85505	275.7902	26.82148	430.9223	15.25857
124.1056	14.40500	279.2376	26.74091	434.3696	13.14682
127.5530	14.08476	282.6850	26.69931	437.8170	11.51014
131.0003	16.32593	286.1324	26.67406	441.2644	10.62645
134.4477	15.31253	289.5797	27.58848	444.7118	9.042961
137.8951	15.79106	293.0271	28.17749	448.1592	7.674279
141.3425	16.79361	296.4745	28.52823	451.6065	5.850107
144.7898	15.02063	299.9219	28.25678	455.0539	4.711496
148.2372	16.75785	303.3693	28.52905	458.5013	2.662608
151.6846	17.77290	306.8166	28.91495	461.9487	0
155.1320	16.90435	310.2640	28.94934	465.3960	0
158.5794	16.76536	313.7114	28.49712		

BURNING RATE DATA FOR JA2 PROPELLANT AT 63C

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
6.894757	1.003829	162.0267	19.81202	317.1588	31.60654
10.34213	1.610058	165.4741	20.46794	320.6062	32.09838
13.78951	1.919629	168.9215	20.83235	324.0535	32.66025
17.23689	3.359048	172.3689	20.97885	327.5009	33.05868
20.68427	2.965538	175.8163	21.52843	330.9483	33.09015
24.13164	3.913065	179.2636	22.01502	334.3957	32.87864
27.57902	3.726248	182.7110	22.20018	337.8430	33.28304
31.02640	4.438566	186.1584	23.02634	341.2904	33.91291
34.47378	4.989850	189.6058	23.17018	344.7378	33.97846
37.92116	5.570011	193.0531	22.88910	348.1852	34.03533
41.36854	5.601568	196.5005	23.15314	351.6326	34.09259
44.81592	6.447962	199.9479	23.56891	355.0799	34.27232
48.26329	6.892640	203.3953	23.79857	358.5273	34.35116
51.71067	8.153979	206.8427	24.47970	361.9747	34.12467
55.15805	8.401530	210.2900	24.43625	365.4221	34.16754
58.60543	8.510442	213.7374	24.93078	368.8694	34.31954
62.05281	9.435066	217.1848	25.74897	372.3168	34.69733
65.50019	9.661900	220.6322	26.0223	375.7642	34.90587
68.94757	9.488223	224.0796	25.94033	379.2116	34.69391
72.39494	10.01503	227.5269	26.44454	382.6590	33.82017
75.84232	10.21554	230.9743	26.15178	386.1063	33.41951
79.28970	10.60998	234.4217	25.97307	389.5537	32.69861
82.73708	11.25148	237.8691	26.20589	393.0011	31.96201
86.18446	11.05801	241.3164	27.15755	396.4485	31.25061
89.63184	12.54651	244.7638	28.02364	399.8959	30.07111
93.07921	12.79244	248.2112	28.77464	403.3432	29.26996
96.52659	12.92358	251.6586	28.67444	406.7906	28.66395
99.97397	13.88118	255.1060	27.84764	410.2380	27.89087
103.4213	13.28807	258.5533	28.14066	413.6854	27.00906
106.8687	14.13925	262.0007	29.08399	417.1327	25.20698
110.3161	15.20298	265.4481	30.05414	420.5801	23.59040
113.7634	15.07972	268.8955	29.58708	424.0275	21.97720
117.2108	15.05735	272.3429	29.07979	427.4749	20.52293
120.6582	15.95381	275.7902	28.64454	430.9223	19.53610
124.1056	15.91695	279.2376	29.46064	434.3696	18.16687
127.5530	16.39436	282.6850	30.16458	437.8170	16.45047
131.0003	17.13741	286.1324	30.23501	441.2644	14.21175
134.4477	17.64234	289.5797	29.89562	444.7118	12.39876
137.8951	18.04256	293.0271	30.49325	448.1592	10.99087
141.3425	18.04567	296.4745	31.39704	451.6065	10.14962
144.7898	18.22032	299.9219	31.66960	455.0539	7.963728
148.2372	18.73572	303.3693	31.48774	458.5013	5.749922
151.6846	18.84882	306.8166	31.16953	461.9487	3.581963
155.1320	20.04253	310.2640	31.55873	465.3960	1.045373
158.5794	18.78022	313.7114	31.55106		

APPENDIX B

COMBUSTIBLE CARTRIDGE CASE CLOSED BOMB

APPARENT BURNING RATE DATA LISTING

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APPARENT BURNING RATE DATA FOR 7/16" DIAMETER
POST IMPREGNATED, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
2.757902	0.33528	64.81071	36.35349	126.8635	47.17669
4.136854	0.50038	66.18966	37.13505	128.2424	46.57902
5.515805	0.617728	67.56861	37.91686	129.6214	45.99533
6.894757	0.831342	68.94757	38.60317	131.0003	45.42485
8.273708	1.140206	70.32652	39.27983	132.3793	44.50740
9.652659	1.46939	71.70547	39.95496	133.7582	43.53128
11.03161	1.885442	73.08442	40.62857	135.1372	42.58665
12.41056	2.3622	74.46337	41.3004	136.5161	41.66006
13.78951	2.949702	75.84232	41.97096	137.8951	40.75887
15.16846	3.559302	77.22127	42.59808	139.2740	39.39235
16.54741	4.191762	78.60022	43.14825	140.6530	38.08450
17.92636	4.889246	79.97918	43.69587	142.0319	36.83203
19.30531	5.679948	81.35813	44.24095	143.4109	35.57752
20.68427	6.541008	82.73708	44.78350	144.7898	33.93719
22.06322	7.441692	84.11603	45.32350	146.1688	32.38703
23.44217	8.374634	85.49498	45.86122	147.5477	30.92094
24.82112	9.320276	86.87393	46.33976	148.9267	29.13303
26.20007	10.27785	88.25288	46.73854	150.3057	27.40736
27.57902	11.25016	89.63184	47.13452	151.6846	25.70378
28.95797	12.22603	91.01079	47.52797	153.0636	23.84145
30.33693	13.21003	92.38974	47.91837	154.4425	22.10054
31.71588	14.21180	93.76869	48.30648	155.8215	20.23287
33.09483	15.19326	95.14764	48.6918	157.2004	18.45818
34.47378	16.19859	96.52659	49.02352	158.5794	16.70532
35.85273	17.20443	97.90554	49.23967	159.9583	14.95907
37.23168	18.19122	99.28450	49.4538	161.3373	13.31645
38.61063	19.19528	100.6634	49.66589	162.7162	11.81658
39.98959	20.21687	102.0424	49.87620	164.0952	10.57757
41.36854	21.18614	103.4213	50.08422	165.4741	9.557512
42.74749	22.16658	104.8003	50.29047	166.8531	8.740648
44.12644	23.15895	106.1792	50.43297	168.2320	8.111998
45.50539	24.16352	107.5582	50.42154	169.6110	7.41045
46.88434	25.09342	108.9371	50.41011	170.9899	6.587998
48.26329	26.03042	110.3161	50.39893	172.3689	5.936996
49.64225	26.97429	111.6950	50.38801	173.7478	5.317236
51.02120	27.92526	113.0740	50.37709	175.1268	4.691634
52.40015	28.85287	114.4529	50.36642	176.5057	4.110482
53.77910	29.72079	115.8319	50.19954	177.8847	3.2385
55.15805	30.59201	117.2108	49.91150	179.2636	0
56.53700	31.46628	118.5898	49.62855	180.6426	0
57.91595	32.34359	119.9687	49.35016	182.0215	0
59.29491	33.22396	121.3477	49.07661	183.4005	0
60.67386	34.00983	122.7266	48.80787	184.7794	0
62.05281	34.79088	124.1056	48.41519	186.1584	0
63.43176	35.57219	125.4845	47.78857	187.5373	0

APPARENT BURNING RATE DATA FOR 1 3/8" DIAMETER, POST IMPREGNATED, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
2.757902	0.768096	64.81071	48.49698	126.8635	61.10478
4.136854	0.959104	66.18966	49.42255	128.2424	60.62802
5.515805	1.240282	67.56861	50.34508	129.6214	59.59627
6.894757	1.53543	68.94757	51.26583	131.0003	58.52591
8.273708	1.969262	70.32652	52.1589	132.3793	57.48604
9.652659	2.489962	71.70547	52.94198	133.7582	56.47486
11.03161	3.144774	73.08442	53.72150	135.1372	55.49163
12.41056	3.866388	74.46337	54.49747	136.5161	54.53532
13.78951	4.65963	75.84232	55.2704	137.8951	53.60466
15.16846	5.5245	77.22127	56.03976	139.2740	52.11597
16.54741	6.505194	78.60022	56.80608	140.6530	50.47742
17.92636	7.602728	79.97918	57.56935	142.0319	48.91582
19.30531	8.79221	81.35813	58.27242	143.4109	47.41189
20.68427	10.05636	82.73708	58.84519	144.7898	45.96815
22.06322	11.35202	84.11603	59.41390	146.1688	44.58131
23.44217	12.68450	85.49498	59.97879	147.5477	42.42587
24.82112	14.04264	86.87393	60.53963	148.9267	40.33545
26.20007	15.41018	88.25288	61.09690	150.3057	38.36593
27.57902	16.77873	89.63184	62.97091	151.6846	36.50894
28.95797	18.18487	91.01079	62.20079	153.0636	34.38067
30.33693	19.52066	92.38974	62.74739	154.4425	31.96844
31.71588	20.88870	93.76869	63.10680	155.8215	29.74441
33.09483	22.28113	95.14764	63.40017	157.2004	27.67558
34.47378	23.58288	96.52659	63.69075	158.5794	25.13685
35.85273	24.90495	97.90554	63.97853	159.9583	22.85009
37.23168	26.24709	99.28450	64.26352	161.3373	20.57577
38.61063	27.55925	100.6634	64.54571	162.7162	18.31721
39.98959	28.79928	102.0424	64.82537	164.0952	16.24279
41.36854	30.05023	103.4213	65.10248	165.4741	14.34896
42.74749	31.31185	104.8003	65.37706	166.8531	12.60398
44.12644	32.58388	106.1792	70.42861	168.2320	11.00201
45.50539	33.74669	107.5582	65.27038	169.6110	9.576308
46.88434	34.89883	108.9371	65.19316	170.9899	8.442452
48.26329	36.05504	110.3161	65.11721	172.3689	7.560056
49.64225	37.21531	111.6950	65.04203	173.7478	6.749034
51.02120	38.37990	113.0740	64.96812	175.1268	6.064758
52.40015	39.48074	114.4529	64.89496	176.5057	5.446014
53.77910	40.52443	115.8319	64.82283	177.8847	4.937506
55.15805	41.56837	117.2108	64.71107	179.2636	4.242054
56.53700	42.61256	118.5898	64.16497	180.6426	3.798062
57.91595	43.65675	119.9687	63.62979	182.0215	3.344164
59.29491	44.70095	121.3477	63.10503	183.4005	2.608834
60.67386	45.71161	122.7266	62.59042	184.7794	0
62.05281	46.64252	124.1056	62.08572	186.1584	0
63.43176	47.57115	125.4845	61.59068	187.5373	0

APPARENT BURNING RATE DATA FOR 2 7/16" DIAMETER, POST IMPREGNATED, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
2.757902	0.61341	64.81071	49.72812	126.8635	71.14616
4.136854	0.72517	66.18966	50.93004	128.2424	70.75322
5.515805	0.931164	67.56861	52.06695	129.6214	70.36663
6.894757	1.191514	68.94757	53.20538	131.0003	69.79843
8.273708	1.547368	70.32652	54.34558	132.3793	68.68668
9.652659	2.007108	71.70547	55.48731	133.7582	67.60413
11.03161	2.487168	73.08442	56.63057	135.1372	66.54927
12.41056	3.059176	74.46337	57.77534	136.5161	65.52158
13.78951	3.725418	75.84232	58.92165	137.8951	64.51955
15.16846	4.412742	77.22127	59.89167	139.2740	63.54267
16.54741	5.20192	78.60022	60.80023	140.6530	62.59017
17.92636	6.094476	79.97918	61.70650	142.0319	61.66078
19.30531	7.058914	81.35813	62.61023	143.4109	60.23254
20.68427	8.09244	82.73708	63.51193	144.7898	58.40247
22.06322	9.170416	84.11503	64.41135	146.1688	56.64454
23.44217	10.27760	85.49498	65.30848	147.5477	54.95518
24.82112	11.42390	86.87393	66.20332	148.9267	53.33161
26.20007	12.60297	88.25288	67.09613	150.3057	51.77002
27.57902	13.82268	89.63184	67.77278	151.6846	50.26787
28.95797	15.08480	91.01079	68.34352	153.0636	48.18786
30.33693	16.37131	92.38974	68.91274	154.4425	45.67529
31.71588	17.68094	93.76869	69.47357	155.8215	43.31462
33.09483	19.03145	95.14764	70.03288	157.2004	41.09491
34.47378	20.35860	96.5[illegible]	70.58837	158.5794	39.00703
35.85273	21.72055	97.90554	71.14057	159.9583	36.59301
37.23168	23.11704	99.28450	71.68921	161.3373	33.61842
38.61063	24.46096	100.6634	72.23455	162.7162	30.90799
39.98959	25.82799	102.0424	72.77633	164.0952	28.43631
41.36854	27.22118	103.4213	73.05979	165.4741	25.51277
42.74749	28.61538	104.8003	73.18095	166.8531	22.67864
44.12644	29.95015	106.1792	73.30059	168.2320	20.10994
45.50539	31.30346	107.5582	73.4187	169.6110	17.44827
46.88434	32.67481	108.9371	73.53579	170.9899	15.10157
48.26329	34.06368	110.3161	73.65136	172.3689	12.88364
49.64225	35.40074	111.6950	73.76591	173.7478	10.97915
51.02120	36.71925	113.0740	73.87920	175.1268	9.392778
52.40015	38.04945	114.4529	73.99121	176.5057	8.216646
53.77910	39.39159	115.8319	74.10196	177.8847	7.249414
55.15805	40.74515	117.2108	74.09053	179.2636	6.341618
56.53700	42.08907	118.5898	73.64780	180.6426	5.536946
57.91595	43.34611	119.9687	73.21296	182.0215	5.06349
59.29491	44.60976	121.3477	72.78522	183.4005	4.536948
60.67386	45.87976	122.7266	72.36510	184.7794	3.62712
62.05281	47.15637	124.1056	71.95210	186.1584	2.86512
63.43176	48.43907	125.4845	71.54570	187.5373	2.07518

APPARENT BURNING RATE DATA FOR 7/16" DIAMETER, BEATER ADDITIVE, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
3.447378	0.35306	72.39494	116.4767	141.3425	173.5665
6.894757	0.98044	75.84232	123.0198	144.7898	170.2478
10.34213	2.149094	79.28970	129.2329	148.2372	167.0685
13.78951	4.364228	82.73708	135.4754	151.6846	161.6031
17.23689	7.474966	86.18446	141.5305	155.1320	156.1360
20.68427	11.39596	89.63184	146.6535	158.5794	150.1554
24.13164	16.45234	93.07921	151.7578	162.0267	142.7769
27.57902	22.02916	96.52659	156.845	165.4741	135.4632
31.02640	27.94838	99.97397	161.3491	168.9215	126.0695
34.47378	34.3662	103.4213	164.9382	172.3689	116.0170
37.92116	41.27423	106.8687	168.4853	175.8163	104.3896
41.36854	48.63719	110.3161	171.9925	179.2636	89.79712
44.81592	56.23483	113.7634	174.6785	182.7110	73.0631
48.26329	64.13017	117.2108	176.2460	186.1584	54.62041
51.71067	71.91121	120.6582	177.7812	189.6058	36.60165
55.15805	79.89951	124.1056	179.2859	193.0531	22.15540
58.60543	87.39530	127.5530	179.5119	196.5005	13.23111
62.05281	95.10522	131.0003	178.6270	199.9479	0
65.50019	102.3559	134.4477	177.7692	203.3953	0
68.94757	109.3650	137.8951	176.9369	206.8427	0

APPARENT BURNING RATE DATA FOR 1 1/2" DIAMETER, BEATER ADDITIVE, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
3.447378	0.282956	72.39494	163.5539	141.3425	183.4761
6.894757	1.13792	75.84232	173.2264	144.7898	176.4355
10.34213	2.706624	79.28970	181.8495	148.2372	169.4685
13.78951	5.465064	82.73708	190.2256	151.6846	162.2325
17.23689	9.763506	86.18446	197.3643	155.1320	155.0819
20.68427	14.73250	89.63184	204.0722	158.5794	147.9651
24.13164	21.89124	93.07921	209.5400	162.0267	139.7
27.57902	29.72866	96.52659	214.0361	165.4741	132.5986
31.02640	38.07282	99.97397	217.8291	168.9215	123.0835
34.47378	46.86833	103.4213	219.9002	172.3689	111.1618
37.92116	56.46978	106.8687	221.9220	175.8163	96.14814
41.36854	66.95795	110.3161	221.5771	179.2636	76.75981
44.81592	77.89011	113.7634	221.1011	182.7110	55.20664
48.26329	88.92590	117.2108	219.0216	186.1584	39.44848
51.71067	99.92080	120.6582	216.1740	189.6058	27.12313
55.15805	110.8951	124.1056	212.4588	193.0531	16.49272
58.60543	121.8331	127.5530	207.7714	196.5005	8.713724
62.05281	132.5590	131.0003	202.5695	199.9479	0
65.50019	143.2232	134.4477	196.5474	203.3953	0
68.94757	153.6519	137.8951	190.1672	206.8427	0

APPARENT BURNING RATE DATA FOR 2 1/2" DIAMETER, BEATER ADDITIVE, COMBUSTIBLE CARTRIDGE CASE DISCS

PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)	PRESSURE (MPa)	RATE (cm/s)
3.447378	0.143002	72.39494	217.4737	141.3425	221.7333
6.894757	0.839978	75.84232	229.1976	144.7898	211.3696
10.34213	2.630424	79.28970	240.8745	148.2372	202.4164
13.78951	6.448044	82.73708	251.4693	151.6846	195.1296
17.23689	11.94181	86.18446	259.9555	155.1320	190.5383
20.68427	18.43201	89.63184	268.3784	158.5794	187.7357
24.13164	27.19578	93.07921	275.0210	162.0267	187.4873
27.57902	37.63289	96.52659	279.4820	165.4741	187.4022
31.02640	48.60671	99.97397	283.8549	168.9215	186.1629
34.47378	60.37376	103.4213	286.5330	172.3689	182.6554
37.92116	73.13447	106.8687	286.4060	175.8163	176.0242
41.36854	86.68181	110.3161	286.2828	179.2636	162.2437
44.81592	100.8471	113.7634	284.8249	182.7110	143.5554
48.26329	115.5313	117.2108	280.1000	186.1584	113.9461
51.71067	130.4993	120.6582	275.5872	189.6058	54.51424
55.15805	145.4434	124.1056	269.6055	193.0531	53.594
58.60543	160.6296	127.5530	261.0358	196.5005	52.832
62.05281	175.2439	131.0003	252.9563	199.9479	52.49265
65.50019	189.9158	134.4477	242.6835	203.3953	0
68.94757	203.5726	137.8951	232.1036	206.8427	0

APPENDIX C

PRESSURE TRANSDUCER POSITION CORRELATION LIST

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GAUGE DESIGNATION	DISTANCE FROM REAR FACE OF TUBE (cm)
P1	9.5
P2	28.6
P3	48.9
P4	76.8
P5	104.8
P6	153.0
P7	229 2
P8	305.4
P9	381.6
P10	457.8
P11	534.0

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APPENDIX D

GUN FIRING PRESSURE VERSUS TIME PLOTS

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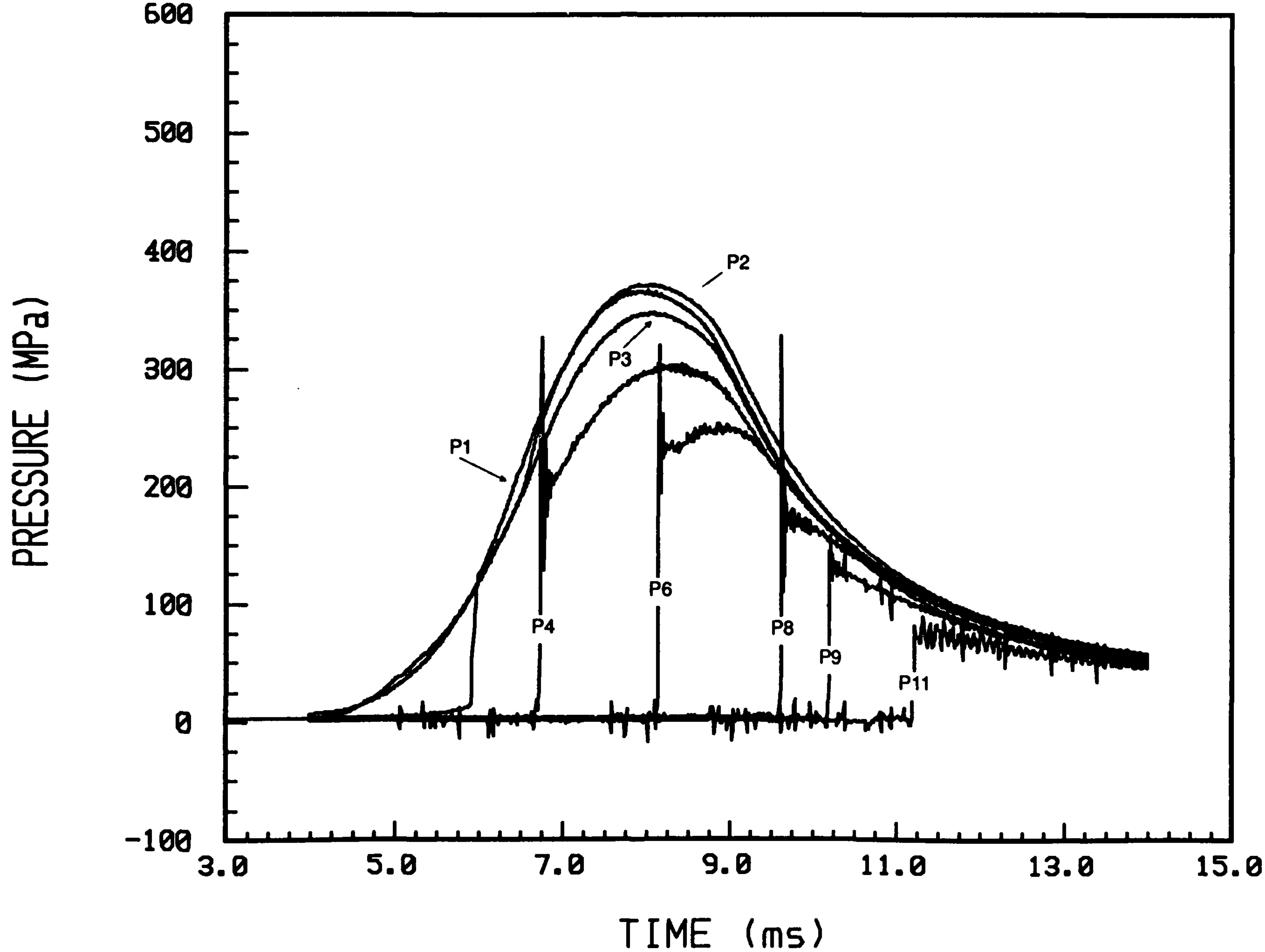

Pressure Time Histories For Round I1. (Inert Case, 21C)

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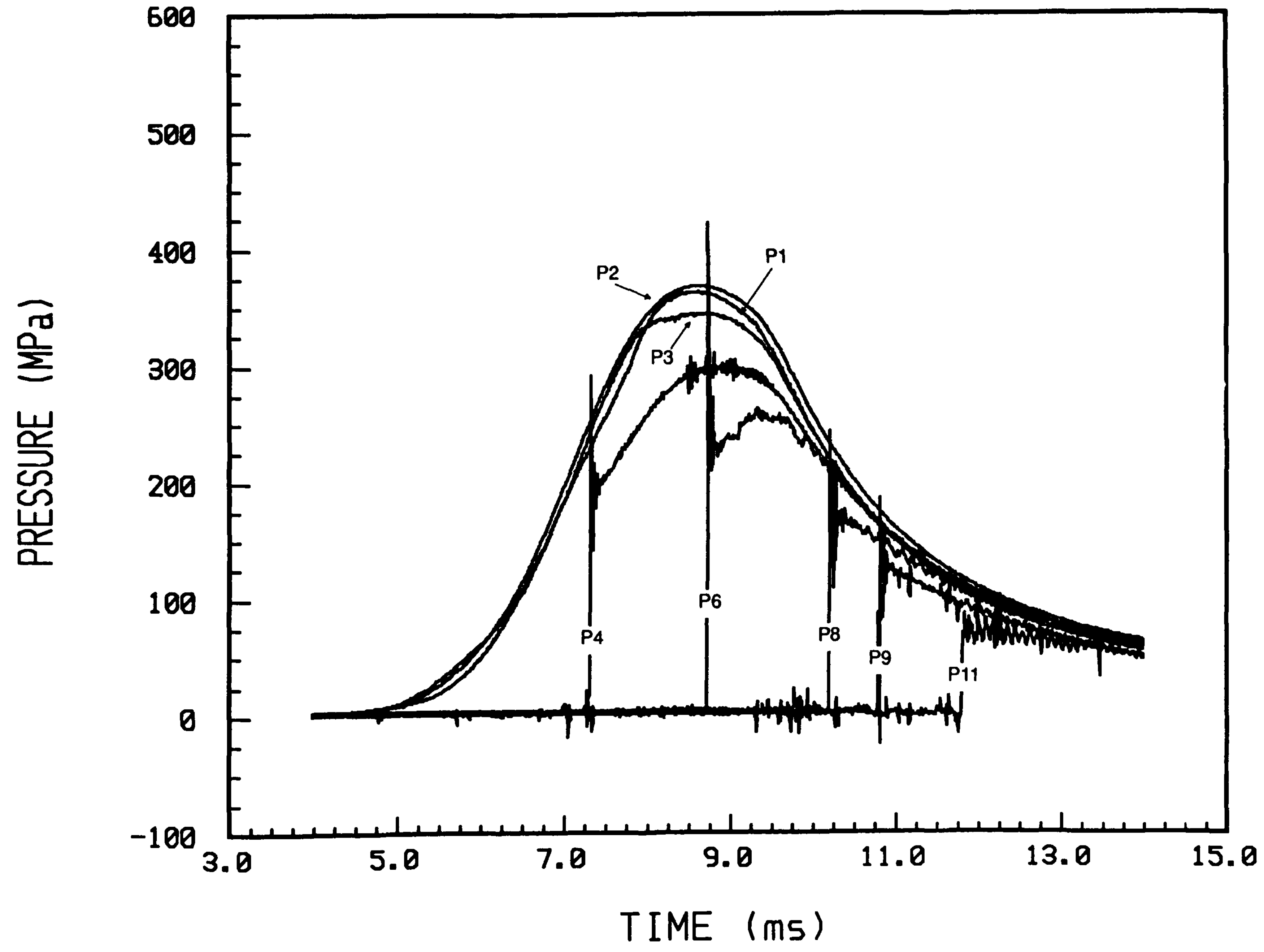

Pressure Time Histories For Round I2. (Inert Case, 21C)

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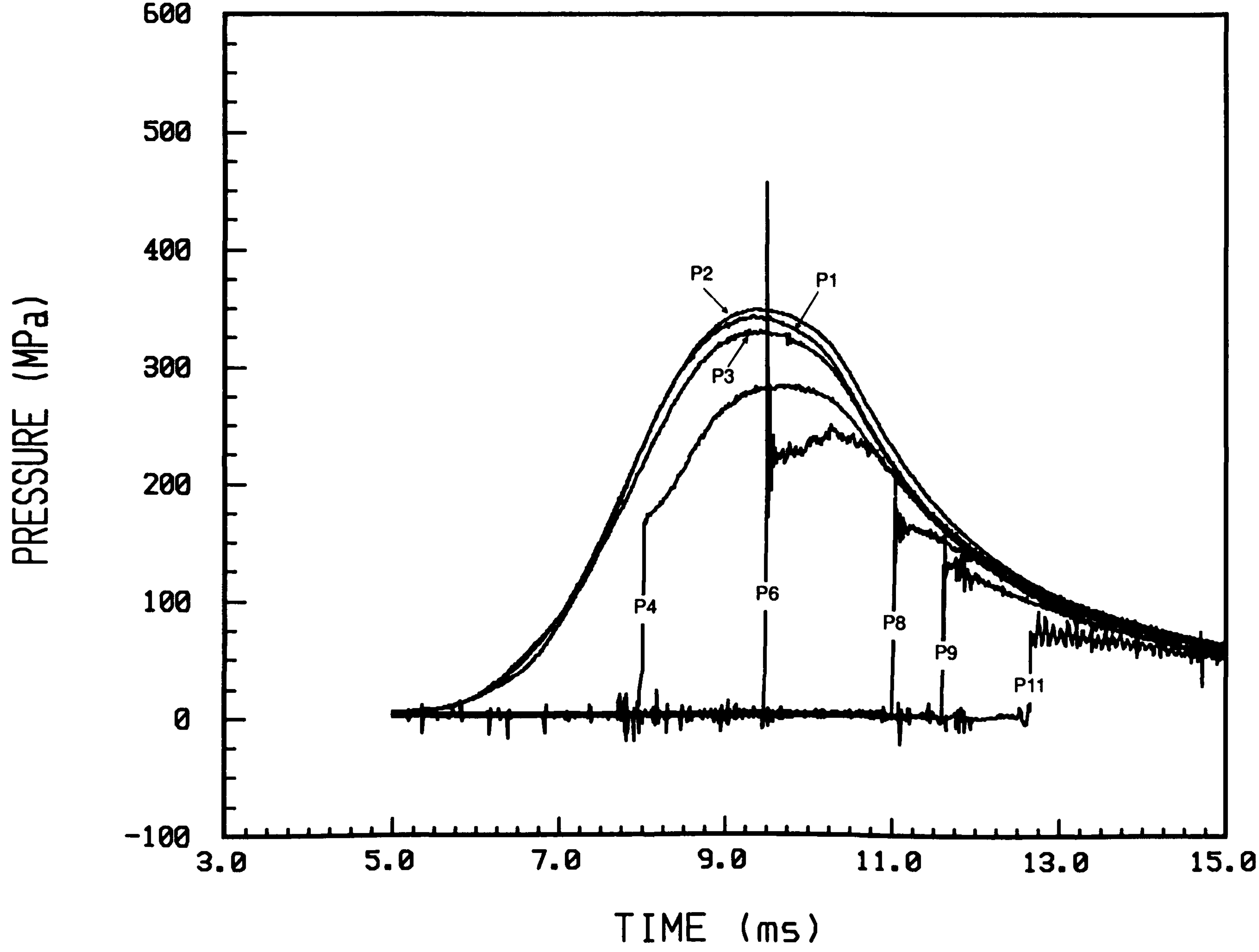

Pressure Time Histories For Round NC1. (No Case, 21C)

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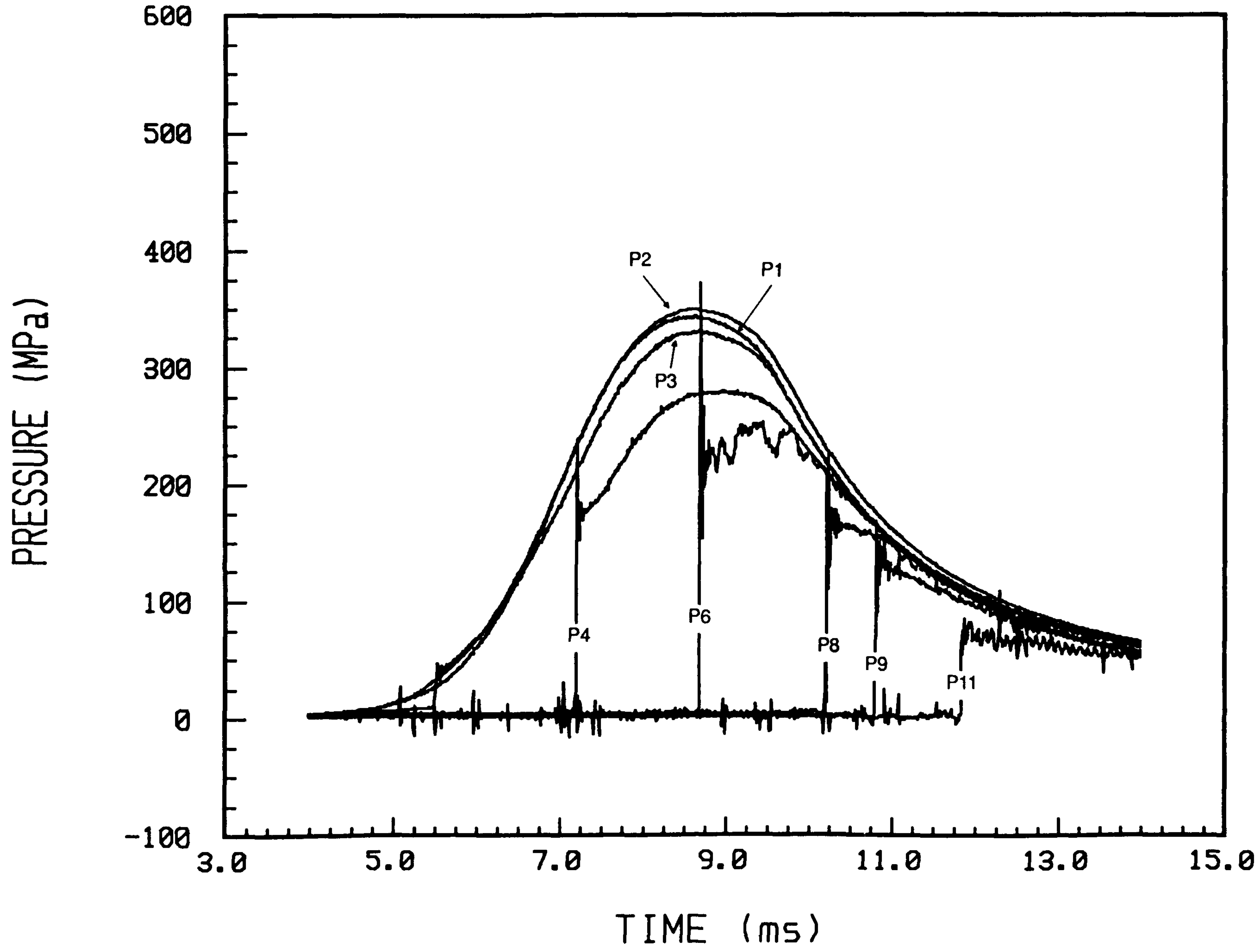

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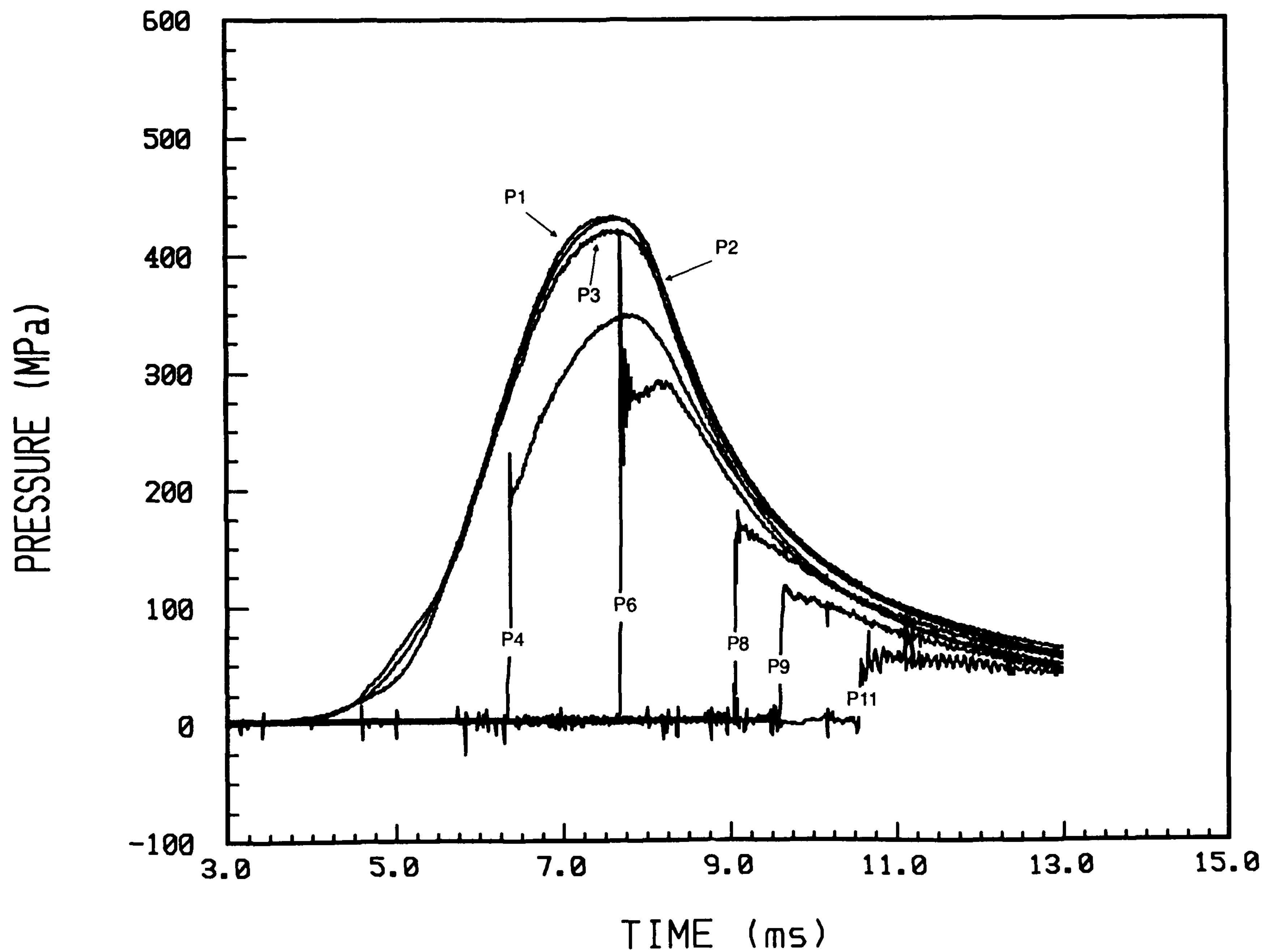

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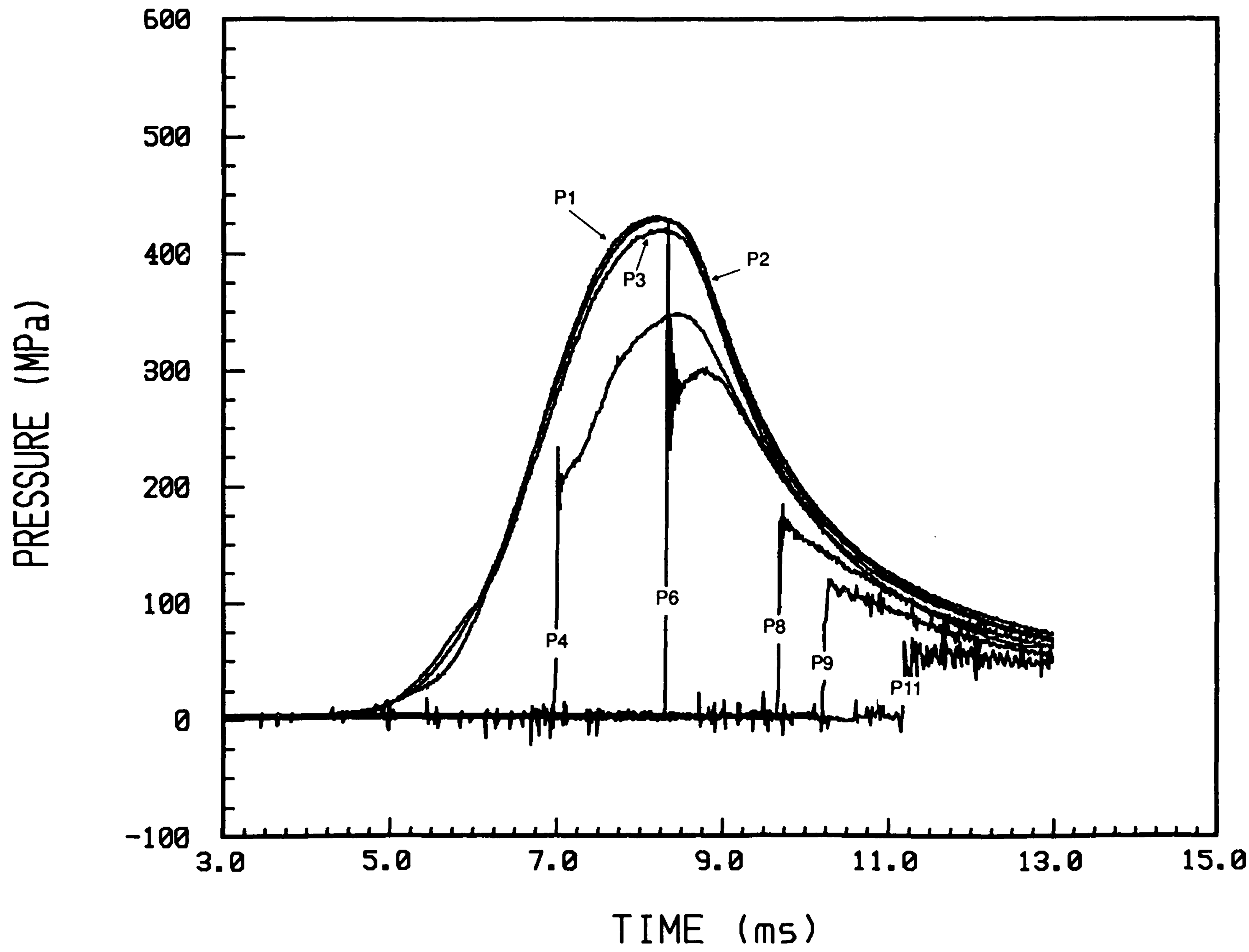

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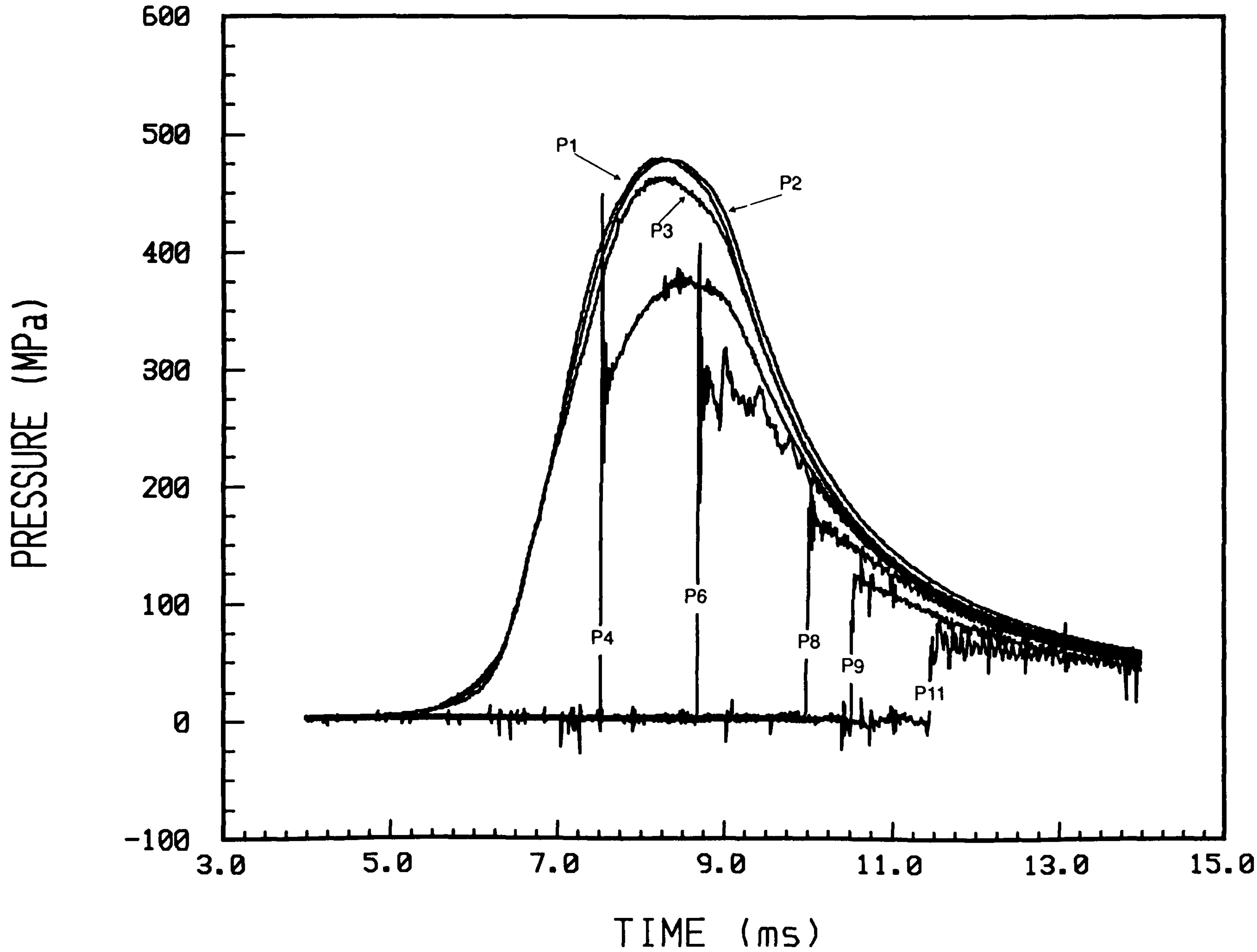

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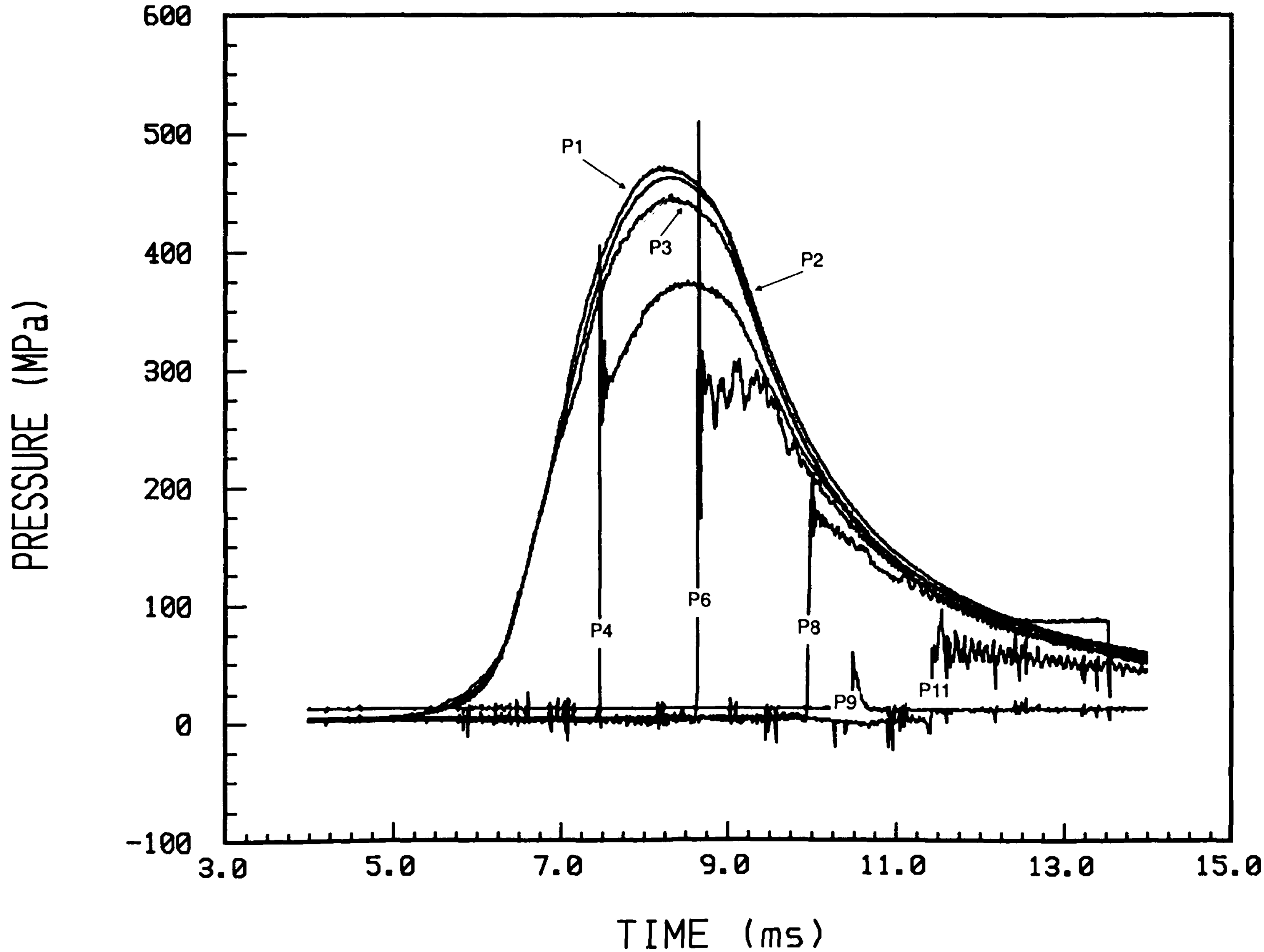

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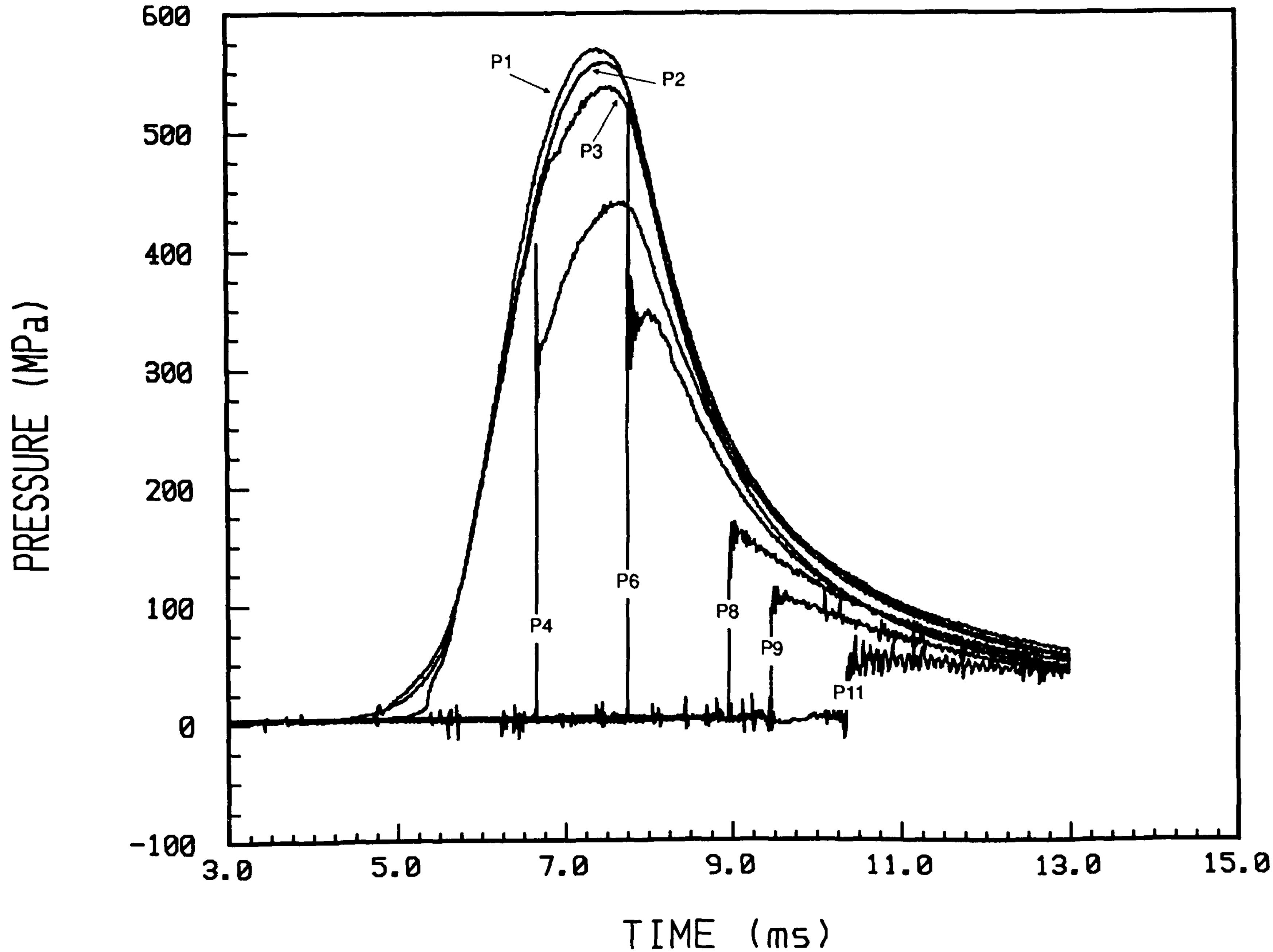

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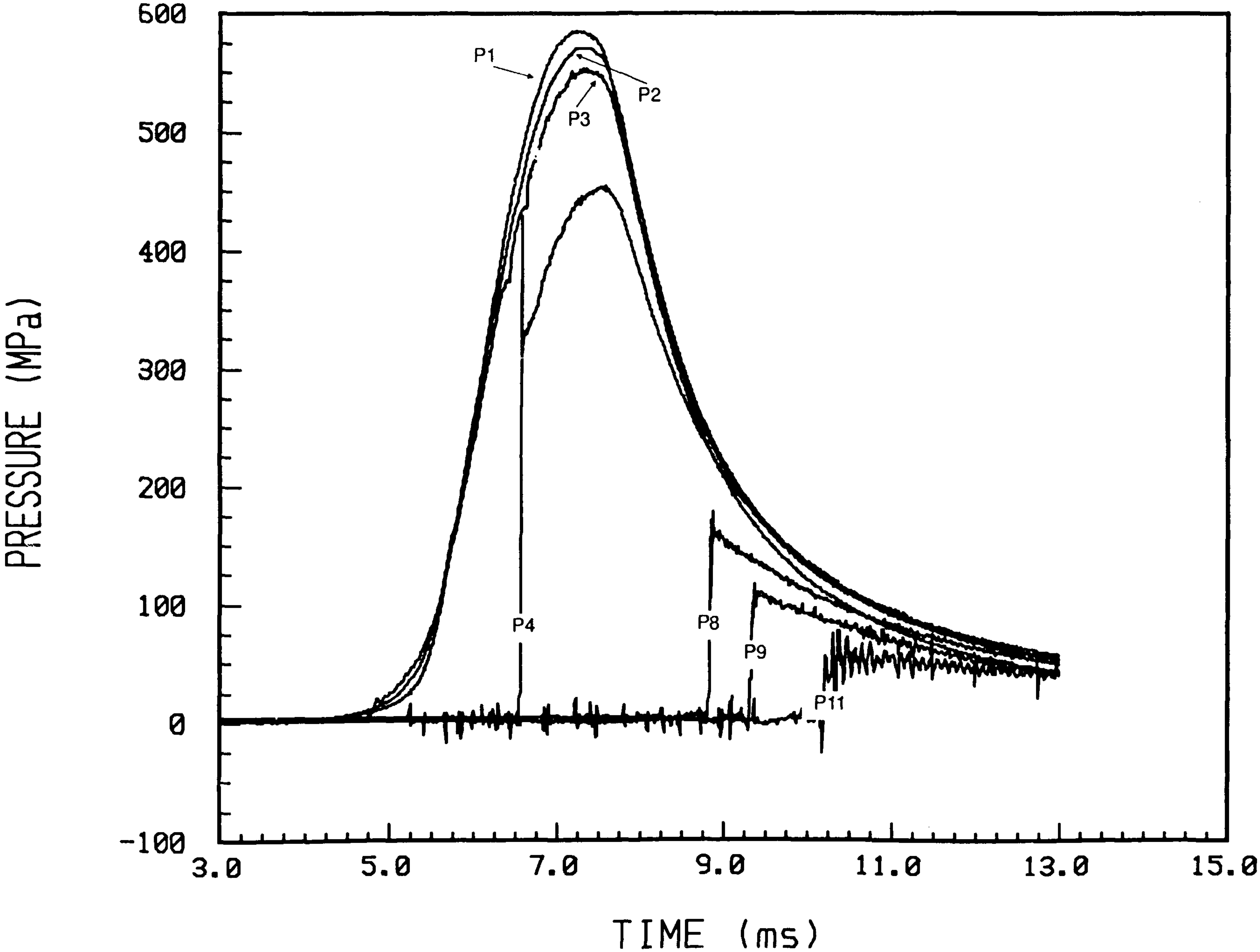

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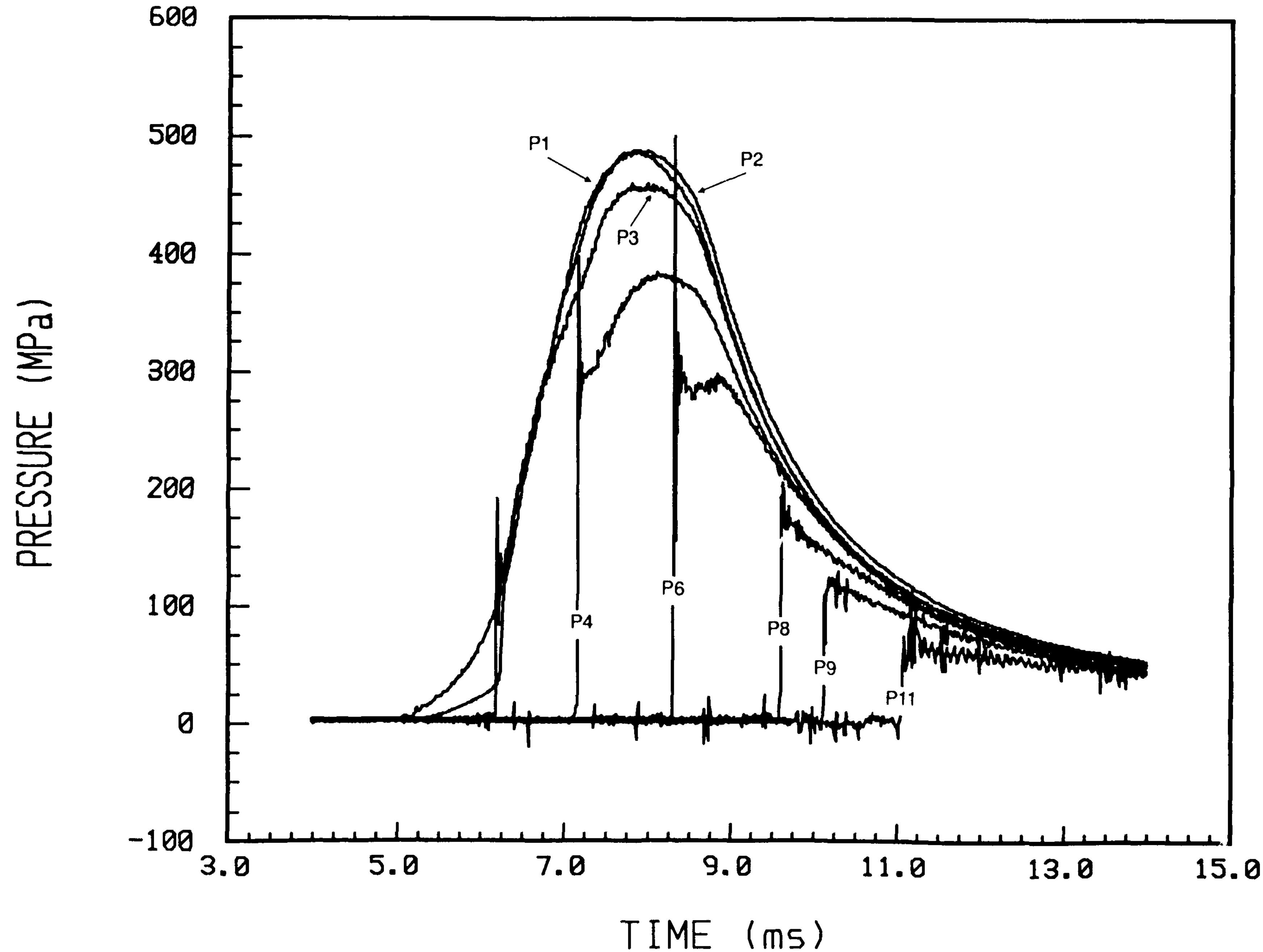

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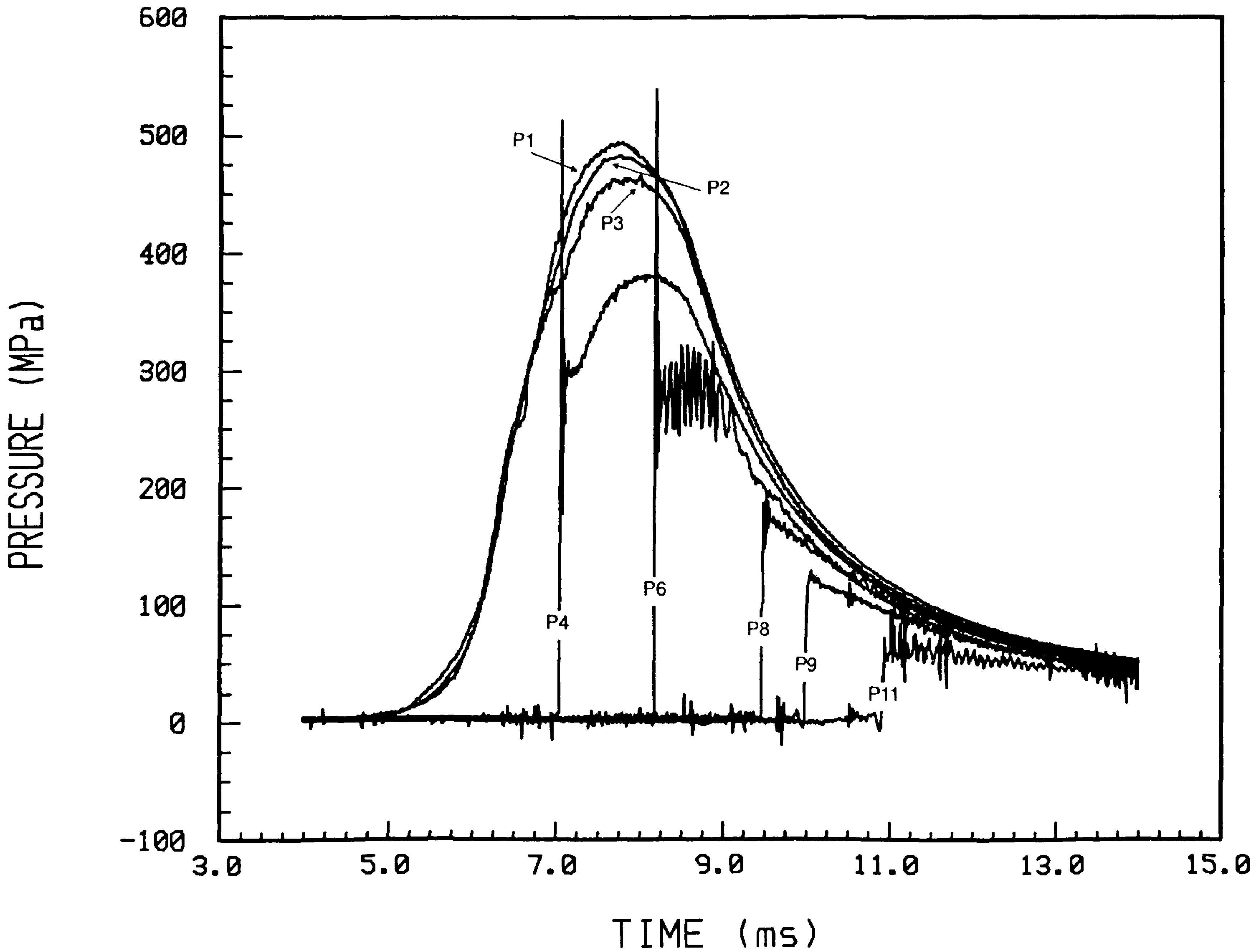

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